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Analysis

Can Land Fragmentation Reduce the Exposure of Rural Households to Weather Variability?☆

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ABSTRACT

Climate change continuously affects African farmers that operate in rain-fed environments. Coping with weather risk through credit and insurance markets is almost inexistent as these markets are imperfect in the African economies. Even though land fragmentation is often considered as a barrier to agricultural productivity, this article aims at analyzing whether land fragmentation, as an insurance alternative, is able to reduce farmers' exposure to weather variability. In order to address this research question, I use the Living Standards Measurement Study-Integrated Surveys on Agriculture (LSMS-ISA) data on Uganda. After dealing with the endogeneity of land fragmentation, I find that higher land fragmentation decreases the loss of crop yield when households experience rainfall anomalies, but remains detrimental for those households that are not exposed to such irregularities. Therefore, policy makers should be cautious while implementing uniform land consolidation programs.

1. Introduction

Global warming is a crucial issue for the African continent and it is expected that its impacts will be even more severe in the future. While Africa is the least responsible for global greenhouse gases (GHG) emissions, it will be the most affected by them owing to low adaptive capacity (Collier et al., 2008). The majority of the population lives in rural areas and is engaged in the agricultural sector which is highly sensitive to weather variability. Because of the lack of irrigation infrastructure, weather conditions affect directly agricultural production and livelihoods (Barrios et al., 2008; Schlenker and Lobell, 2010; Kahsay and Hansen, 2016). Also, climate change increases the frequency and the severity of extreme event, such as floods and droughts. As a result, a great part of the African population has already experienced a variety of stresses and shocks (Barrios et al., 2008). These extreme events have serious impacts on agricultural production, so as gradual changes in climate.

These effects are amplified by the limited capacity of African countries to deal with it. The possibilities to cope with weather risk through credit and insurance markets are almost inexistent since these markets are imperfect in the African economies.[1] In absence of such formal risk-spreading mechanisms, land fragmentation can be an alternative mean for risk reduction, be it exogenously imposed or chosen. This article aims at verifying if this feature of land fragmentation is valid for households that face rainfall irregularities.

Land fragmentation is the practice of farming a number of spatially separated plots of owned or rented land by the same farmer (McPherson, 1982). It is a phenomenon that is observed in many countries especially in the developing ones. The literature classifies the causes of land fragmentation into two categories of possible explanations: i) "supply-side" factors such as inheritance process and population pressure and ii) "demand-side" explanations that consider fragmentation as choice made by farmers. In the developing world, fragmentation arises as a result of a mixture of both aspects, supply side and demand side factors. According to the World Agricultural Census by FAO, the average number of parcels operated by a farmer is 3.5 worldwide during 1995–2005.

Land fragmentation is often considered as detrimental for agricultural sector development. Empirical evidence suggests that higher fragmentation of land holdings reduces agricultural output and agricultural productivity (Wan and Cheng, 2001; Rahman and Rahman, 2009; Van Hung et al., 2007; Tan et al., 2010). Another obstacle to enhancing agricultural productivity associated with land fragmentation is the distance between parcels. In particular, when parcels are

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[1] There are insurance products present on the African continent, such as crop insurance and index-based insurance, but their take-up rate is very low.

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dispersed, travel time and costs in displacing labor and machines can increase (Shuhao et al., 2008). In addition, land fragmentation can prevent farmers from using machinery (Foster and Rosenzweig, 2011). As well, it can generate fencing costs and conflicts among neighbors (Demetriou, 2013).

However, no consensus is established in the empirical literature regarding a robust negative impact of land fragmentation on agricultural outcomes.[2] For instance, Blarel et al. (1992) find that the level of land fragmentation has no significant impact on yield and therefore reject the hypothesis that fragmentation is inefficient in the case of Ghana and Rwanda.

Land fragmentation can in fact provide benefits to farmers: it reduces exposure to risk; it allows for crop scheduling and for use of several agro-ecological zones. In particular, land fragmentation reduces risk because it offers a greater variety of soils and growing conditions. This is especially the case in areas composed of micro-environments where fiends are affected by various degrees of moisture, wind, hail, pests, isolation and drainage (Bentley, 1987). As a consequence, it can facilitate risk management through seasonal and spatial diversification of crop production (Blarel et al., 1992; Bentley, 1987; Van Hung et al., 2007). Two dimensions of land fragmentation can improve the ability of farmers to diversify weather risk: the physical distance between the parcels and the different agro-ecological characteristics of the different parcels. McCloskey (1976) is among the first economists to document the ability of scattered parcels to reduce the crop production risk. Blarel et al. (1992) found that land fragmentation reduces the variability of agricultural output per acre. Fragmentation also allows for adjustments of household labor across seasons since crop scheduling is easier when parcels are scattered in different locations with different agro-ecological characteristics (Fenoaltea, 1976). Furthermore, land fragmentation improves agro-biodiversity as crops are better matched with the operated soil types (Di Falco et al., 2010).

This article aims at analyzing the ability of fragmented land to reduce their exposure of farmers to rainfall variability. More precisely, the objective is to study empirically whether households with higher degree of fragmented land incur smaller reductions in their agricultural income when they are subject to rainfall irregularities. The contribution of the paper is twofold: i) it provides a quantitative approach on the incidence of land fragmentation on agricultural income by considering rainfall variability, which to the best of my knowledge, has not been addressed by the literature; and ii) it contributes to the debate on advantages and disadvantages of land fragmentation in the case of Uganda.

Land fragmentation is measured by the number of parcels that the household owns and also by a Simpson Index calculated for these parcels. This index combines the number of parcels and the distribution of area among the different parcels. An important issue rarely considered in the literature, is the endogeneity of land fragmentation. Farmers may choose their level of land fragmentation in order to cope with production risk, even though this choice is highly dependent on the extent to which land markets are dynamic. Also, farmer's choice of fragmentation can be affected by some unobserved individual characteristics that influence the level of agricultural income as well (management ability, entrepreneurial spirit). To address this issue, I instrument the fragmentation in operated land with the fragmentation in inherited land, as inherited land fragmentation is exogenously imposed on the household (Foster and Rosenzweig, 2011). I use data from the Living Standards Measurement Study-Integrated Surveys on Agriculture (LSMS-ISA) for the years 2005/2006, 2009/2010, 2010/2011 and 2011/2012 established by the World Bank. I find that the impact of land fragmentation on crop yields depends on rainfall variability: it increases yields when households face rainfall variability (by mitigating crop losses), but decreases them otherwise. The results show that the higher the rainfall deviation, the higher the beneficial effect of land fragmentation. These results are robust across different empirical specifications.

Because of the widely perceived inefficiencies of land fragmentation, some countries like Kenya, Tanzania and Rwanda, have adopted land consolidation programs. In the case of Uganda, land fragmentation seems to offer risk-reduction possibilities to farmers that are subject to rainfall irregularities, but it remains detrimental for farmers that do not experience such anomalies.The policy implication of this article is not to fully support land fragmentation, but rather to draw attention on the careful design of consolidation policies by taking into account the economic and agro-ecological circumstances. Even within a country, a uniform consolidation process might not be equally favorable to all farmers. Fragmentation can particularly offer benefits in areas characterized with various micro-environments, where land, labor and insurance markets are imperfect and mechanization of the agricultural activities are at very low stage of development (Bentley, 1987).[3] If the labor market is imperfect, labor supply is fixed by the household endowment and there is an important need to spread labor temporally. Moreover, farmers fail to cultivate land due to land market imperfections rather than its small size or fragmentation. Therefore, addressing land, labor and insurance market imperfections might be a priority for enhancing agricultural productivity. Engaging in uniform consolidation process that is often very costly should be supported with indeed cost/benefit analysis of both land consolidation and fragmentation for farmers operating in different environments.

The article is organized as follows. Section 2 describes the land tenure systems and climate variability in Uganda. Section 3 describes the data, the measures of land fragmentation and rainfall anomalies, and gives the descriptive statistics. Section 4 introduces the econometric specification and discusses the endogeneity problems. Section 5 presents the results of the main estimation equation and includes robustness checks and discussion. Finally, Section 6 includes a summary of the results, policy implications and further research ideas.

2. Background

The Constitution of Uganda includes customary, freehold, mailo and leasehold tenure systems recognized by the Land Act of Uganda 1998. The mailo system represents a sub-division of land where the basic unit is a square mile, hence the name mailo. Mailo land is owned with assigned individual property rights certified by a land title. Similarly, freehold land holders have full ownership over their land. This implies that holders can use land for any purpose and sell, let, lease and dispose it off. Leasehold system is a system of owning land for a particular period of time. The leasehold transactions are contractual and allow both contract parties to define the terms and conditions of access and usage.

Customary tenure system dominates the other systems. According to the FAO, it represents 75% of the total land which makes it the most common form of tenure in the country. Land is therefore mainly governed by customs, rules and regulations of a particular community. Due to these regulations, the main cause of land fragmentation is the inheritance system. In Uganda, population growth together with the traditional inheritance protocols are supposed to be the most important driver of the increased land fragmentation (Nkonya et al., 2004). For instance, when the head of a household dies, his land is sub-divided

[2] Such divergence between authors might be also linked to how yields are measured. A growing literature takes into consideration measurement errors due to self-reported land surfaces and uses more objective measures such as GPS coordinates measures when studying land size and productivity relationship. This might change the direction of the debate. In this article I use both self-reported land size and GPS measures as robustness check.

[3] Low adoption of technology will make difficult for farmers to exploit scale economies of consolidated land especially if labor markers are imperfect.

among his sons.[4] The higher the number of male members of the family the lower the piece each member gets. But, division of land can be made also premortem through gifts or transfers and sometimes can be unequal among family members. Also, land can be acquired as a gift from other members of the extended family than the father. This phenomenon of land sub-division continues with each passing generation on the customary freehold lands. According to the Ugandan economist Eric Kashambuzi, Ugandan farmers tend to consider fragmentation as beneficial as it allows to grow different crops on parcels with different characteristics. Even though inheritance process drives fragmentation, for some farmers it is also a personal choice. However, in February 2015, the president Yoweri Museveni strongly recommended farmers to stop land fragmentation, following its recent increase due to inheritance practices.

Uganda lies across the equator. Its climate is humid with very hot periods during the year. It has two rainfall seasons, one from March to June and another from August to November. Uganda has experienced extreme weather episodes in the last years, especially in the North. As reported by the Ugandan Ministry of Water and Environment, between 1991 and 2000, Uganda experienced seven droughts. Nevertheless, the climate is suitable for crop production and the rainfall intensities are expected to grow. It is expected that the rainfall distribution across seasons will become more and more irregular. According to the World Bank indicators, about 84% of the population of Uganda lives in rural areas in 2014. As the agricultural production is of a subsistence type and rain-fed, Ugandan farmers are much exposed to weather variability and verifying whether land fragmentation can allow for reducing its impact on agricultural income is crucial.

3. Data and Descriptive Statistics

In this study, I use data from the Living Standards Measurement Study-Integrated Surveys on Agriculture (LSMS-ISA) for the years 2005/2006, 2009/2010, 2010/2011 and 2011/2012 established by the Bill and Melinda Gates Foundation and implemented by the Living Standards Measurement Study (LSMS) within the Development Research Group at the World Bank. The Uganda National Panel Survey (UNPS) sample includes economic and social information on about 3200 households (with about 2000 households that are engaged in cultivation of crops). These households were previously interviewed in the 2005/2006 Uganda National Household Survey (UNHS). The sample also includes households that were randomly selected after 2005/2006. The sample is representative at the national, urban/rural and main regional levels (North, East, West and Central regions).

Table 1 presents definitions and the summary statistics of the dependent and explanatory variables used in the estimations. The dependent variable is crop yield in value. It represents the total crop production evaluated at each crop prices at community level and divided by the total cultivated land. The main variable(s) of interest are the total number of cultivated and owned but not cultivated parcels and the Simpson index.[5] The average number of cultivated and owned but not cultivated parcels by households in the sample is 2.3 with the maximum being at 18. Considering the number of parcels with different texture and different slope, the average number of different parcels is 1.29 and 1.36 respectively. According to Fig. 1, the distribution of parcels in the sample is skewed. The percentage of household with 1 parcel is 32.5, with 2 parcels is 34 and with 3 parcels is 19. Only 15.5% of households have a degree of fragmentation that exceeds 3 parcels. By definition, the Simpson index is comprised between zero and one and the sample average is 0.35. This indicates that, on average, land shares are unevenly distributed among the different parcels. The evolution of land acquisition of the households is given in Table 2. The share of inherited land has increased over the years and the share of inherited parcels stands for half of the total parcel holdings of a given household. However, households also choose to some extent the number of parcels that they will operate, with purchased and rented parcels representing the other half of operated and owned land. Household heads have on average 46 years, are mostly male (about 70%) and have on average attended only primary school. Only 2% of the households did not receive any education. The average number of adult members of the households is around 3. The average size of the cultivated land is 4.6 acres and the soil quality is mostly fair.

The data used to construct the rain deviation variable is the TS3.21 dataset from the Climatic Research Unit of the University of East Anglia. It is monthly average data on precipitations from high-resolution grids, 0.5×0.5 degrees, that cover more than one century (1901–2012). The precipitation anomalies are constructed following Marchiori et al. (2012) as deviations at time t in the district d from the long run annual mean divided by the long run annual standard deviation of the given district, as in the following equation:

$$RAINDEV_{dt} = \frac{RAIN_{dt} - \mu_{dLR}}{\sigma_{dLR}} \tag{1}$$

where $RAIN_{dt}$ corresponds to the annual level of rainfall in the district d, μ_{dLR} is the long run (LR) rainfall mean in the same district and σ_{dLR} is the standard deviation. According to Table 1, the average rain deviation in the 80 districts included in the sample is 0.7 with the minimum being 0 and the maximum rain deviation being 2.6 in absolute terms. Fig. 2 shows the absolute rainfall deviation for the different districts in Uganda in different years in the sample. The size of absolute rainfall deviation increases over the period which might be linked to the consequences of climate change.

4. Empirical Strategy

Following the literature on firm size and productivity (see among others Carletto et al., 2013), I estimate the following equation at household level:[6]

$$\log\left(\frac{Y_{ht}}{A_{ht}}\right) = \alpha_0 + \alpha_1 X_{ht} + \alpha_2 F_{ht} + \alpha_3 \log(A_{ht}) + \alpha_4 Z_{ht} + \alpha_5 RAINDEV_{dt} + \\ + \alpha_6 RAINDEV_{dt} {}^* F_{ht} + \mu_h + \eta_t + \varepsilon_{ht} \tag{2}$$

where Y_{ht} represents the value of total agricultural output of household h in time t. The total agricultural output is evaluated at mean community prices for each crop that the given household produces. The dependent variable is the ratio between the value of the agricultural production and the total land cultivated in acres, and this equals total agricultural yield per acre in value. A_{ht} represents the total cultivated land net of land under fallow. X_{ht} accounts for the household socio-economic characteristics such as the number of adults which is a proxy for the labor endowment, education, gender and age of the household head. Errors, ε_{ht}, are clustered at district level.

The degree of land fragmentation of the household is given by the variable F_{ht}. Land fragmentation is usually measured simply by the number of parcels that the household operates.[7] This variable includes the parcels that a household owns and rents. Among the owned parcels, households mainly inherit the different parcels and a lower part of them

[4] However, woman begin to take part in the process of inheritance and have property rights over parcels, even though they mainly get these rights through marriage.

[5] More precisely the type of parcels included are cultivated, both owned and rented, and non-cultivated owned parcels that might be under fallow for example, as the aim is to account for total actual fragmentation.

[6] The semi-logarithmic functional form has better 'goodness of fit' (R-squared, F-test) compared to the double-logarithmic functional form.

[7] Parcels under fallow are also included in the number of parcels operated by the household.

Table 1
Variable definition and descriptive statistics.

Variable	Definition	Mean	Standard deviation	Min	Max
agprod	Total agricultural production in Ugandan Shillings (UGX)	25,420,750	254,658,569	0	18,001,293,312
yield	Agprod/cultivated land	11,799	125,000	0	6,000,432
yield in log	Agprod/cultivated land, ratio in log	6.206	2.464	0	15.607
Land fragmentation					
n	Number of parcels	2.28	1.38	1	18
n type	Number of parcels with different soil texture	1.29	0.51	1	4
n topography	Number of parcels with different slope	1.36	0.57	1	5
Simpson index	Calculated as described by Eq. (3)	0.35	0.27	0	1
Household characteristics					
sex	The gender of the HH head; equals 1 if the HH head is male 0 if it is female	0.712	0.453	0	1
age	The age of the HH head	46.384	15.313	13	100
education	The highest school level achieved by the HH head 0-no education, 1-primary, 2-secondary	1.026	0.659	0	2
adults	HH members above 16 years	2.960	1.686	0	24
Land characteristics					
cultivated land	Cultivated land in acres	4.614	37.355	0 3000	
soil quality index	Weighted index of soil quality with: level 1 being good quality and level 3 being poor quality	1.704	0.703	0	3
Weather characteristics					
rain dev	Rain deviation in absolute terms from the long run mean divided by the long run standard deviation at time t in district d	0.668	0.614	0.005	2.628

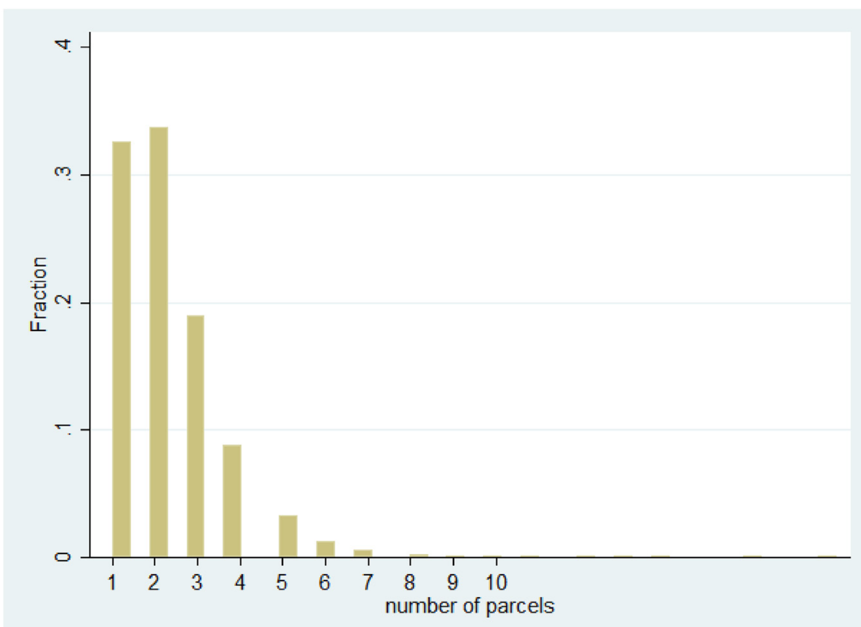

Fig. 1. Distribution of parcels.

Table 2
Land acquisition.

Parcels	2005/2006	2009/2010	2010/2011	2011/2012
Inherited	40%	47%	50%	53%
Purchased	25%	26%	25%	23%
Rented	27%	26%	23%	22%
Other	8%	1%	2%	2%

is purchased.

The Simpson Index is also used in the literature (Blarel et al., 1992; Shuhao et al., 2008). It is defined as

$$SI_{ht} = 1 - \sum_{i=1}^{n} a_{it}^2 / \left(\sum_{i=1}^{n} a_{it}\right)^2 \tag{3}$$

where n is the number of parcels and a_{it} is the size of parcel i in time t. A Simpson index close to zero means that the land of the household is completely consolidated; there is only one parcel. The closer the value to one, the more fragmented the land of the household is. The value of the Simpson index is therefore determined by the number of parcels, the average size of the parcels and the parcel size distribution. This index does not take into account the total size of the land holdings of the farmer, the different characteristics of the parcels and the distance to the parcels. Therefore, Z_{ht} controls for land quality.

I include a variable $RAIN_{dt}$ that measures annual deviation in

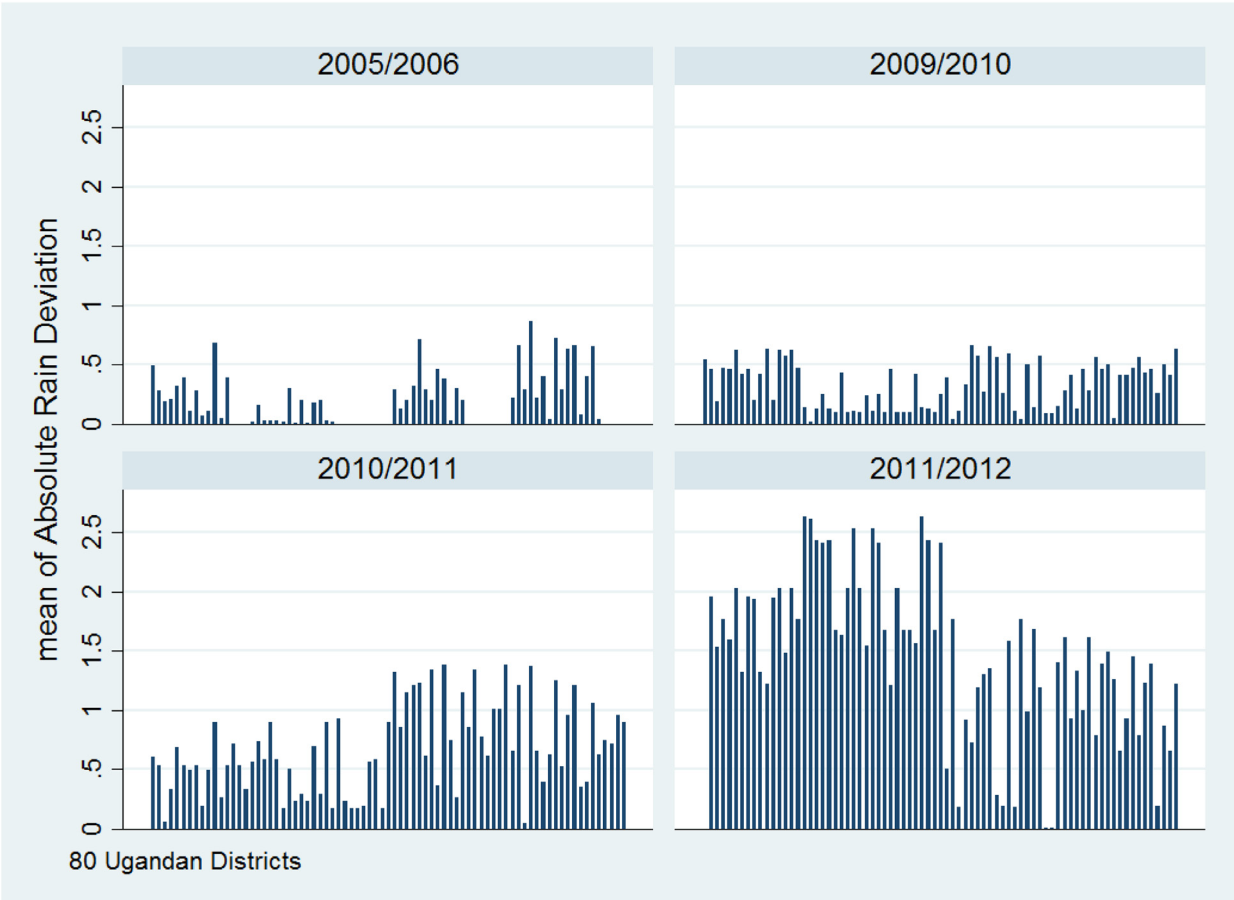

Fig. 2. Average rain deviation in the 80 districts.

rainfall from the long run mean at time t in the district d where the household h lives divided by the long run standard deviation. $RAIN_{dt}$ measures the rainfall anomalies to which households are exposed. For sake of simplicity in interpretation, this variable is expressed in absolute terms. In addition, according to precipitation data used in this study, there were more positive (and extreme) rainfall anomalies in the different districts of Uganda than negative, on average. The interaction term between the rainfall anomalies and the degree of fragmentation tests for a possible difference in impact of rainfall variability on income between households that have different levels of land fragmentation. I expect that when households face the same rainfall anomalies, more fragmented land holdings should lower the incidence on income compared to more consolidated land holdings. Finally, μ_h and η_t stand for household and time fixed effects.

A concern while estimating Eq. (2) is that land fragmentation is affected by some unobserved factors that influence agricultural income (management ability, entrepreneurial spirit). Farmers can also choose their level of land fragmentation in order to deal with production risk. This is the case when land markets exist and land can be traded or rented. However in the case of Uganda, as land markets are incomplete we can assume that trading land is not entirely feasible. Still, the degree of land fragmentation of the household can be at least partially chosen as shown in Table 2. In order to deal with this endogeneity, I instrument the fragmentation in operated land with the fragmentation in inherited land, as inherited land fragmentation is exogenously imposed on the household through the inheritance process (Foster and Rosenzweig, 2011). The other first-stage equation is

$$F_{ht} = \beta_0 + \beta_1 X_{ht} + \beta_2 Ninherited_{it} + \beta_3 ln(A_{ht}) + \beta_4 Z_{ht} + \beta_5 RAIN_{dt} + \mu_h + \eta_t + \varepsilon_{ht} \quad (4)$$

where *Ninherited* is the number of parcels inherited by the household i in time t. The interaction variable, $RAIN_{dt} * F_{ht}$, in Eq. (2) is also endogenous and it is instrumented with the interaction term between rain anomaly and number of inherited parcels. The other first stage equation is therefore given as

$$RAIN_{dt}{*}F_{ht} = \gamma_0 + \gamma_1 X_{ht} + \gamma_2 RAIN_{dt}{*}Ninherited_{it} + \gamma_3 ln(A_{ht}) + \gamma_4 Z_{ht} + \mu_h + \eta_t + \varepsilon_{ht} \quad (5)$$

5. Results

In this section the results from the estimation of Eq. (2) are presented. In Table 4, I use the number of parcels n as a measure for land fragmentation and in Table 6 this is measured with the Simpson index described before. In both tables Panel fixed effects (FE) and Panel instrumental variable (IV) estimations are included. Columns (2) and (4) in each table include the soil quality index that is constructed for the last three rounds, as the data on land quality is missing from the first round, thus these estimations are run on a smaller sample.

5.1. First Stage Results

Before discussing the second stage results, I comment on the results for the first stage estimation and the validity of the instruments. Table 3 gives the first stage results of land fragmentation measures and suggests that the number of inherited parcels has a positive and significant impact on the number of owned parcels and on the Simpson index. If the land markets in Uganda were perfect, the coefficient in column (1) in Table 3 of the inherited fragmentation would have the value 0 as households can freely decide about the number of parcels they want to

Table 3
First stage estimation - inherited number of parcels as instrumental variable.

	n	Simpson index
Instrument		
n inherited	0.581*,**,***	0.0881***
	(0.0293)	(0.00495)
Control variables	Yes	Yes
Validity tests		
F-statistic	27.56	25.6
Stock and Yogo 10% IV size	7.03	7.03
Observations	8342	8342
R-squared	0.265	0.162
Number of HHID	2718	2718

Robust standard errors in parentheses.
* $p < 0.1$.
** $p < 0.05$.
*** $p < 0.01$.

Table 4
The impact of fragmentation on yield - count measure.

Yield (log)	Panel FE (1)	Panel FE (2)	IV panel FE (3)	IV panel FE (4)
n	−0.254***	−0.451***	−0.251***	−0.768***
	(0.0311)	(0.0484)	(0.0815)	(0.109)
Rain deviation	−0.553***	−0.706***	−1.109***	−1.737***
	(0.0894)	(0.110)	(0.188)	(0.227)
n * rain deviation	0.181***	0.238***	0.444***	0.697***
	(0.0366)	(0.0433)	(0.0867)	(0.0997)
Sex	−0.904***	−1.006***	−0.890***	−0.986***
	(0.168)	(0.267)	(0.170)	(0.278)
Age	0.0749***	0.0220*,**	0.0755***	0.0199
	(0.00945)	(0.0121)	(0.00847)	(0.0123)
Adults	0.0962***	−0.0649*	0.0886***	−0.0706*
	(0.0264)	(0.0386)	(0.0274)	(0.0418)
Cultivated land (log)	−0.950***	−0.959***	−1.023***	−0.967***
	(0.0603)	(0.0833)	(0.0690)	(0.0947)
Primary education	0.672***	0.669***	0.667***	0.633***
	(0.130)	(0.182)	(0.136)	(0.195)
Secondary education	1.281***	1.594***	1.258***	1.496***
	(0.187)	(0.250)	(0.196)	(0.270)
Land quality index		−0.933***		−0.897***
		(0.0508)		(0.0551)
Constant	4.299***	9.702***		
	(0.417)	(0.602)		
Observations	8342	6251	8342	6251
R-squared	0.080	0.139	0.070	0.115
Number of HHID	2718	2477	2718	2477

Standard errors in parentheses.
* $p < 0.1$.
** $p < 0.05$.
*** $p < 0.01$.

Table 5
Quantifying the effects.

Rain deviation	0	0.5	1
↑ n by 1 parcel	↓ 30%	↓ 3%	↑ 21%
	Yield		

operate. The closer this coefficient is to 1, the more the household land fragmentation is determined by inheritance. The F-statistic is higher than 20 in both estimations and higher than the Stock and Yogo 10% IV size which indicates that the instruments are statistically appropriate.[8]

5.2. Main Results

The estimation results of Eq. (2) are presented in Tables 4 and 6. The measure of fragmentation changes between Tables 4 and 6, but the results are analogous which makes the empirical analysis robust. Treating the endogeneity of the variable(s) of interest improves the statistical significance and increases the magnitude of the coefficients in both tables. Therefore, I focus on column (4) in each table while interpreting the results. In order to quantity the results, we have to take into consideration that the estimation equation is in a semi-logarithmic functional form of the estimation equation. According to Table 4, an increase of the number of parcels by one reduces the agricultural yield by 25% in the case when farmers do not experience any rainfall anomaly. As expected, higher fragmentation leads therefore to lower yield per acre. Regarding the impact of rainfall variability, for a farmer with two parcels, one rain deviation more will decrease the yield by 22%. If a farmer has the average number of parcels, that is 2.35, then the yield loss is reduced to the level of 6.6%. Considering the interaction term between land fragmentation and rain deviation, if we assume a rain deviation equal respectively to 0.5 and 1 standard deviation, then the agricultural yield decreases by 3% in the first case and increases by 19% in the second case when the number of parcels increases by one. These net effects are shown in Table 5.

These results are robust to the alternative measure of land fragmentation, the Simpson index, in Table 6. If there is no rain deviation, an increase of the Simpson index by 0.1 units decreases the agricultural yield by 15%. When there is one standard deviation in rainfall, then the increase of the index of 0.1 leads to an increase of the yield by 8.4%, which offsets almost by half the impact of the previous case. If the Simpson index is equal to 0.3, 0.35 (average) or 0.5, then one standard deviation in rainfall reduces the yield by 24%, 12.5% and increases the yield by 23% in the last case. This confirms our *ex ante* hypothesis that land fragmentation can be beneficial for those households that are exposed to higher weather irregularities. The results demonstrate that the higher the rainfall deviation, the higher the beneficial effect of more fragmented land holdings.

From the estimated model (2), we can predict the yield for each level of rain deviation by considering the degree of land fragmentation. This is illustrated in Fig. 3.[9] For households that have one parcel and do not face any rain deviation, the predicted yield is the highest. On the contrary, households that operate 5 parcels have the lowest level of predicted yield when there are no rain deviations. If rain deviation increases, the yield of the most consolidated land ($n = 1$) decreases and the yield of the most fragmented land ($n = 5$) increases. Land fragmentation can therefore be perceived as detrimental for households that are not exposed to rainfall variability. But, land fragmentation can be beneficial for households that face higher rainfall variability and do not have access to other forms of insurance. Considering the results in Table 4 column (1), the threshold above which a household can realize benefits form land fragmentation is 0.6 standard deviation in rainfall. If household faces a standard deviation in rainfall that is higher then 0.6, then having more than 3 parcels to operate will not decrease its yield.

When considering the other covariates in Tables 4 and 6, having a household head that is older increases the yield, experience might be positively associated with agricultural efficiency. In addition, a household head with primary or secondary education earns a higher agricultural yield compared to household heads with no education. The impact is even higher when the head has secondary education compared to the primary education. Concerning labor as production factor,

[8] When regressing inherited land fragmentation on the different household characteristics such as sex, age and education, no single covariate has a significant impact. We can consider this as another validity check that the instrument is exogenous to household characteristics and satisfies the exclusion restrictions.

[9] The illustration is based on the results in Table 4, column (1).

Table 6
The impact of fragmentation on yield - Simpson index.

Yield (log)	Panel FE (1)	Panel FE (2)	IV panel FE (3)	IV panel FE (4)
Simpson index	−0.917***	−1.694***	−1.506***	−4.744***
	(0.176)	(0.263)	(0.537)	(0.697)
Rain deviation	−0.362***	−0.447***	−0.945***	−1.568***
	(0.0679)	(0.0841)	(0.154)	(0.193)
Simpson * rain deviation	0.635***	0.824***	2.343***	3.932***
	(0.153)	(0.182)	(0.435)	(0.512)
Sex	−0.916***	−1.016***	−0.880***	−0.936***
	(0.168)	(0.271)	(0.172)	(0.291)
Age	0.0757***	0.0236**	0.0749***	0.0198
	(0.00946)	(0.0122)	(0.00851)	(0.0124)
Adults	0.0925***	−0.0657*	0.0813***	−0.0816*
	(0.0263)	(0.0387)	(0.0276)	(0.0426)
Cultivated land (log)	−1.001***	−1.025***	−1.030***	−1.006***
	(0.0591)	(0.0829)	(0.0634)	(0.0911)
Primary education	0.674***	0.687***	0.658***	0.630***
	(0.130)	(0.183)	(0.137)	(0.202)
Secondary education	1.292***	1.652***	1.246***	1.545***
	(0.187)	(0.251)	(0.197)	(0.274)
Land quality index		−0.933***		−0.874***
		(0.0505)		(0.0565)
Constant	4.076***	9.247***		
	(0.417)	(0.600)		
Observations	8342	6251	8342	6251
R-squared	0.076	0.131	0.059	0.079
Number of HHID	2718	2477	2718	2477

Standard errors in parentheses.
* $p < 0.1$.
** $p < 0.05$.
*** $p < 0.01$.

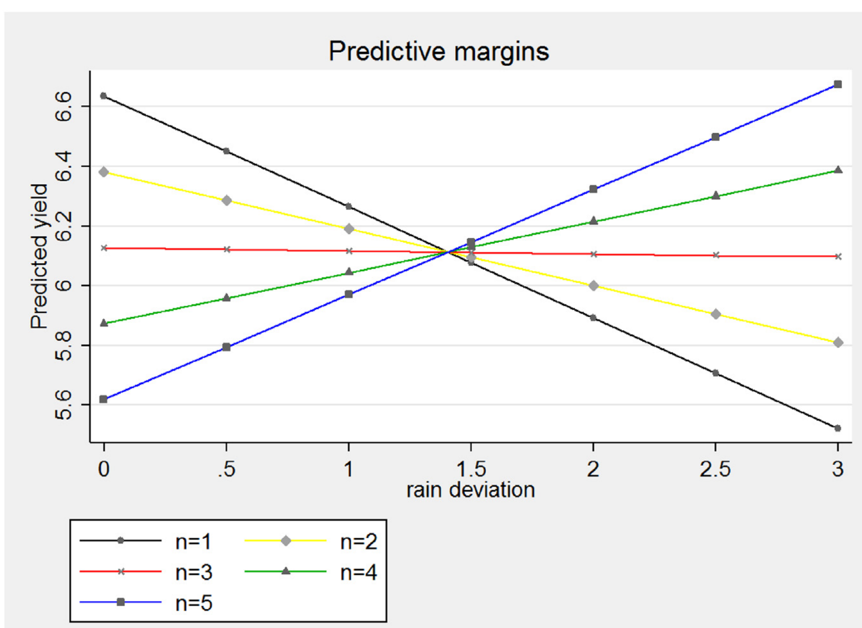

Fig. 3. Predicted yield for different levels of rain deviation and number of parcels.

labor and land, an increase in the number of adults has a positive impact on the agricultural yield. However, there is a negative relationship between the size of the cultivated land and the yield. In the literature it was shown that in the case of some developing countries there is an inverse relationship between farm size and productivity (Carletto et al., 2013). The higher the level of the soil quality index, that refers to a worse soil quality, the lower is agricultural yield, as expected.

5.3. Robustness Tests

As a first robustness check, Table 7 includes the number of parcels with different soil type and soil topography which gives a more detailed aspect of risk diversification of a land holding. The results are consistent with the ones previously found. The higher the number of parcels with different soil types, the lower is the impact of agricultural yield of a rain deviation. However, this is not verified for the number of parcels with

Table 7
The impact of fragmentation: different soil type and slope.

Yield (log)	Panel FE (1)	Panel FE (2)
n soil type	−0.773***	−0.762***
	(0.116)	(0.116)
n topography	−0.180	−0.154
	(0.126)	(0.126)
Rain deviation	−1.306***	−0.737***
	(0.146)	(0.157)
n soil type * rain deviation	0.639***	0.530***
	(0.128)	(0.129)
n topography * rain deviation	−0.0117	−0.0704
	(0.121)	(0.124)
Sex	−0.925***	−1.024***
	(0.268)	(0.269)
Age	0.0171	0.0207*,**
	(0.0115)	(0.0123)
Adults	−0.0488	−0.0621
	(0.0406)	(0.0387)
Cultivated land (log)	−1.044***	−1.025***
	(0.0906)	(0.0839)
Primary education	0.747***	0.665***
	(0.181)	(0.182)
Secondary education	1.707***	1.617***
	(0.256)	(0.254)
Quality index		−0.949***
		(0.0510)
Constant	8.751***	10.03***
	(0.612)	(0.634)
Observations	6251	6251
R-squared	0.072	0.133
Number of HHID	2477	2477

Standard errors in parentheses.
* p < 0.1.
** p < 0.05.
*** p < 0.01.

Table 8
The impact of fragmentation including distance.

Yield (log)	Panel FE (1)	IV panel FE (2)	Panel FE (3)	IV panel FE (4)
n	−0.441***	−0.760***		
	(0.049)	(0.110)		
Simpson			−1.412***	−4.703***
			(0.247)	(0.703)
Rain deviation	−0.710***	−1.726***	−0.518***	−1.559***
	(0.110)	(0.226)	(0.107)	(0.193)
Land frag. * rain deviation	0.242***	0.694***	0.169***	3.916***
	(0.043)	(0.099)	(0.042)	(0.511)
Distance	−0.118*	−0.136*	−0.126*	−0.104
	(0.068)	(0.073)	(0.069)	(0.078)
Sex	−1.014***	−0.994***	−1.043***	−0.942***
	(0.266)	(0.278)	(0.270)	(0.291)
Age	0.022*	0.020	0.024**	0.020
	(0.012)	(0.012)	(0.012)	(0.012)
Adults	−0.064*	−0.069*	−0.062	−0.081*
	(0.039)	(0.042)	(0.039)	(0.043)
Cultivated land (log)	−0.955***	−0.958***	−1.045***	−1.000***
	(0.083)	(0.094)	(0.082)	(0.090)
Primary education	0.671***	0.634***	0.695***	0.631***
	(0.182)	(0.195)	(0.183)	(0.202)
Secondary education	1.591***	1.493***	1.659***	1.542***
	(0.250)	(0.270)	(0.252)	(0.274)
Land quality index	−0.930***	−0.895***	−0.933***	−0.871***
	(0.051)	(0.055)	(0.051)	(0.057)
Constant	9.868***		9.339***	
	(0.608)		(0.604)	
Observations	6250	6250	6250	6250
R-squared	0.139	0.116	0.131	0.080
Number of HHID	2477	2477	2477	2477

Standard errors in parentheses.
* p < 0.1.
** p < 0.05.
*** p < 0.01.

different topography. A piece of land and with low degree of steepness can contribute to lower water infiltration and water runoffs. This might be a possible explanation why a higher number of parcels with different slope might not reduce the impact of rainfall variability on productivity. The other covariates have similar impacts as in the previous empirical specification.

A second robustness check consists to include the average distance to the parcels in order to account for the time cost. The information on distance is only given for the three last survey years, thus the sample size is lower. The average distance is calculated as the average of the time that it takes for a farmer to arrive to the different parcels. The results are given in Table 8. As expected, the higher this average distance, the lower the agricultural yield. The previous results and conclusions on land fragmentation and its interaction with rain deviation do not change when I control for the distance.

Further, we might expect that households with higher number of parcels can potentially overestimate the size of their holdings. Subjective appreciation of the size of land holdings might be biased and therefore the calculation of agricultural yield could appear inaccurate. One of the advantages of the dataset used in this article is that GPS measurements of parcel size are included for 70% of the parcels. In order to verify whether the previous estimates are robust, I test whether there is a significant difference between the subjective measures of acreage of farmers and the GPS measurement.[10] I only take into account households that have both measures for each of their parcels (which is the case for 45–55% of the households in the sample). I test the difference between the two measures and the null hypothesis that this difference is equal to zero cannot be rejected for each year of the survey and all years combined. Moreover, I run the test for each year of the survey by level of land fragmentation and no significant difference is found for the different number of parcels. These tests seem to indicate that the main results are robust, at least with regards to the measurement error in land holdings.

Following the literature on the effect of climate change on diverse economic outcomes, if precipitation is highly correlated with temperature, the coefficient of precipitation will reflect the combined effect of the two variables (Auffhammer et al., 2013). For the period studied in this analysis, the correlation coefficient between temperature and precipitation in levels is around 0.2 and it is significant at 1% level. As the correlation between the two weather variables is not significantly high, I include temperature anomalies as a robustness check in the empirical specification to verify if the previous results of precipitation are consistent.

Table 9 shows the results where both weather variables are included and interacted with the level of fragmentation. When comparing the previously obtained results to the results included in Table 9, we observe that there is no difference in terms of magnitude and statistical significance concerning the land fragmentation measures and precipitations anomalies. The coefficients of the interaction terms between rain deviations and temperature deviations with the degree of fragmentation are positive and statistically significant which confirms the ex ante hypothesis. Temperature anomalies seem not to be harmful for agricultural productivity in Uganda for the period studied. However, this estimate has to be considered with caution for the following reasons. Considering the period studied, the temperature varies to lower extent over time compared to rainfall and household fixed effects capture to some extent the lower variability of temperature of the District where they belong.[11] Second, temperature

[10] I run a paired t-test in STATA for both measures.

[11] The overall standard deviation is mainly driven by the cross-sectional variation rather than the within variation of temperature across districts.

Table 9
The impact of fragmentation including temperature.

Yield (log)	IV panel FE (1)	IV panel FE (2)
n	−0.646***	
	(0.191)	
Simpson		−3.804***
		(1.049)
Rain deviation	−1.728***	−1.651***
	(0.171)	(0.134)
Temp. deviation	2.518***	2.569***
	(0.188)	(0.148)
Land frag. * rain deviation	0.236***	1.259***
	(0.079)	(0.378)
Land frag. * temp. deviation	0.203*,**	1.173***
	(0.083)	(0.402)
Sex	0.135	0.157
	(0.193)	(0.197)
Age	−0.011	−0.012
	(0.008)	(0.008)
Adults	0.047	0.040
	(0.029)	(0.029)
Cultivated land (log)	−1.027***	−1.027***
	(0.066)	(0.063)
Primary education	−0.106	−0.133
	(0.147)	(0.147)
Secondary education	0.095	0.076
	(0.201)	(0.201)
Land quality index	−0.283***	−0.276***
	(0.041)	(0.041)
Observations	6250	6250
R-squared	0.600	0.594
Number of HHID	2477	2477

Robust standard errors in parentheses.
* $p < 0.1$.
** $p < 0.05$.
*** $p < 0.01$.

Table 10
The impact of fragmentation on crop diversity.

Number of crops	Panel FE (1)	IV panel FE (2)
Number of parcels	0.224*,**,***	0.255***
	(0.029)	(0.061)
Control variables	Yes	Yes
Observations	6250	6250
Number of HHID	2477	2477

Robust standard errors in parentheses.
Note: The set of controls are cultivated land, labor, sex, age and education of the HH head and land quality index.
* $p < 0.1$.
** $p < 0.05$.
*** $p < 0.01$.

anomalies are only positive, meaning that there are only increases in temperature whereas precipitation anomalies can be both positive and negative for the period considered. Third, as temperature increases systematically in Uganda since the years 2000, households might have adapted to this trend and they might more easily predict an increase in temperature then rainfall irregularity. Finally, temperature might have non-linear effects on diverse agricultural and economic outcomes, therefore estimates in Table 9 should be considered with caution (Schlenker and Roberts, 2009).

5.4. Discussion: Indirect Effects of Land Fragmentation

Finally, as discussed previously, the literature that studies the benefits of land fragmentation has argued that fragmentation leads to higher crop diversity. Di Falco et al. (2010) quantify this relationship. Because of the different agro-ecological characteristics of the fragmented parcels, crop diversification is more feasible as it matches the soil type and quality to the features of the crops. Land fragmentation

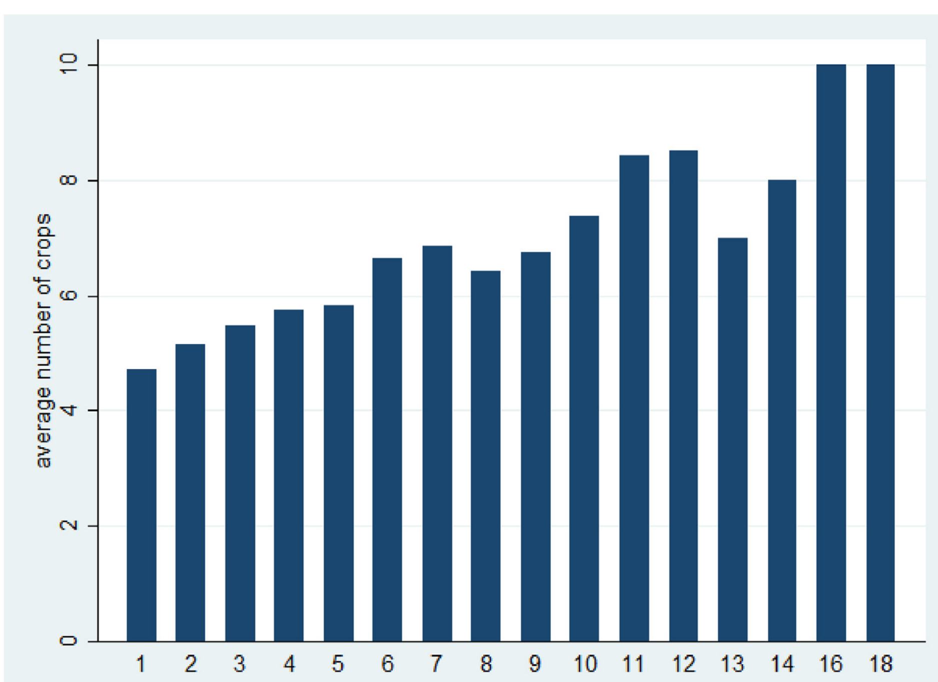

Fig. 4. Crop number per number of parcels.

could therefore have an indirect effect on the exposure of households to rainfall variability through the ability to increase the crop diversity. Fig. 4 shows the average number of crops cultivated for each number of parcel. The number of cultivated crops increases with the level of fragmentation. For households cultivating only one crop, the average number of parcels for these household is 1.5. More consolidated/fragmented land holdings lead to higher crop specialization/diversification. In Table 10, I present the results from a reduced-form estimation that tests the impact of land fragmentation on crop diversity similarly to Di Falco et al. (2010).

The impact of the number of parcels on the number of cultivated crops is positive and significant at 1% level of statistical significance. These estimations seem to confirm that one of the mechanisms by which land fragmentation reduces the impact of rainfall deviations on agricultural yield could indeed be through an increase in crop diversity. These results as well as the previous ones are in line with Di Falco et al. (2010).

Both studies find that fragmentation has a direct negative effect on agricultural outcomes on yield and profitability respectively. Simultaneously, higher fragmentation degree increases farm crop diversity, and has in turn a positive effect on profitability. According to Di Falco et al. (2010), the negative incidence of fragmentation on agricultural incomes can be compensated by the positive role that fragmentation has on diversity. In a similar vein, this article finds that fragmentation can reduce yield loss of farmers facing rainfall irregularities and this finding could operate through a crop diversification mechanism.

6. Conclusion

The aim of this article is to explore the role of land fragmentation when agricultural households face rainfall variability. Even though land fragmentation is mainly considered as detrimental for agricultural productivity, there is some evidence that it can allow for production risk reduction. I use the LSMS-ISA data from Uganda to analyze this feature of land fragmentation in face of rainfall irregularities. After instrumenting for the level of fragmentation, I find that higher land fragmentation decreases the loss of crop yield when households experience rainfall anomalies. The results further show that the higher the deviation, the higher the beneficial effect of land fragmentation. These results are robust when accounting for different measures of land fragmentation and including average distance between the parcels and temperature deviation. I also find that labor endowment and education are crucial for agricultural productivity.

The results of this article indicate that developing countries should be cautious with the implementation of uniform policy of land consolidation. In the case of Uganda, land fragmentation reduced yields of farmers that do not experience rainfall anomalies, but it offers diversification benefits to those that are subject to rainfall irregularities. A systematic consolidation process might not be uniformly beneficial to all farmers. Fragmentation can be particularly beneficial in areas characterized with various micro-environments, where land, labor and insurance markets are imperfect and limited use of mechanization. Promotion and engagement in consolidation policy should be supported with accurate cost/benefit analysis of both land fragmentation and land consolidation for farmers operating in different environments.

Further research could study to which extent land fragmentation could offer risk reduction benefits in the case of other weather and environmental irregularities such as pests attacks and crop diseases. Another extension of this study would be to examine the effects of land consolidation on yields in different economic and agro-ecological setups. Finally, to the extent that land fragmentation is at least partly a farmer's free choice, another research extension would be to study under which circumstances farmers choose to operate more or less fragmented land.

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